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VENTILATION AND SAFETY RELATED PROBLEMS WHEN DRIVING HEADINGS IN COAL MINES WITH FULL FACE TUNNEL BORING MACHINES

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November 1983

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MICROMEDIA

37 pp

ENERGY RESEARCH PROGRAM
COAL RESEARCH LABORATORIES
DIVISION REPORT ERP/CRL 83-22(TR)

VENTILATION AND SAFETY RELATED PROBLEMS WHEN DRIVING HEADINGS IN COAL MINES WITH FULL FACE TUNNEL BORING MACHINES

by

A.W. Stokes* and L.B. Geller**

SUMMARY

This report relates the information which was gathered by the authors during a recent visit to the Federal Republic of West Germany. Included is a review of the equipment and methods currently employed to ventilate tunnel boring machines in their coal mines. This is followed by a brief review of ventilation associated problems which have been experienced by, improvements suggested by, and safety research currently being conducted by West German personnel.

Lastly, a list of conclusions is made.

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PROBLÈMES DE VENTILATION ET SÉCURITÉ RELIÉS AU CREUSEMENT DE GALERIES DANS LES MINES DE CHARBON AU MOYEN DE FOREUSES À SECTION ENTIÈRE

Par

A.W. Stokes* et L.B. Geller**

SOMMAIRE

Le présent rapport traite des informations recueillies par les auteurs lors d'une récente visite en Allemagne de l'Ouest. Le rapport comprend un compte rendu de l'équipement et des méthodes actuellement utilisés pour la ventilation des foreuses de galeries dans les mines allemandes. Il comprend aussi un bref compte rendu des études faites par le personnel allemand sur les problèmes éprouvés relatifs à la ventilation et les améliorations possibles ainsi que la description de la recherche actuelle sur la sécurité minière. Enfin, on a dressé une liste de conclusions.

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INTRODUCTION

After satisfactory trials with a modified experimental 4 m diameter full-face tunnel boring machine (TBM) at the Cape Breton Development Corporation's (CBDC) Donkin-Morien mine, a prototype 7.6 m diameter TBM is now being developed and constructed for CBDC by Lovat Tunnel Equipment of Toronto (1, 2). The experimental TBM was used for driving a short length of the planned no. 2 decline on a -20% gradient, starting at the portal. Ventilation, fire safety and related problems were, therefore, of relatively minor concern. However, four long headings (up to 3.8 km) will be driven with the full size prototype TBM; thus ventilation and safety will be of immediate and major concern.

While CBDC's use of a full-face TBM in an underground coal mine is a pioneering effort in Canada, much valuable experience has already been accumulated in this field in the Federal Republic of West Germany. The various Mine Inspectorates, Collieries and Testing Laboratories involved have very kindly agreed to share their experiences with the authors, for the benefit of the Canadian coal mining industry. This report is written on the basis of personal discussions with the German colleagues in question (see APPENDIX I) and on the information obtained from voluminous documentation also graciously supplied (3 to 15).

TBM VENTILATION SYSTEMS

The problem of how to safely ventilate headings in coal mines has been a concern of the industry for some time. The introduction of full-face TBMs and boom type roadheaders, which can create long, large diameter tunnels at very high advance rates has only served to exacerbate the ventilation problem. Full-face TBMs add to the problem further as their construction does not allow the ventilating airstream free access to the heading face. TBMs have now been used in the coal mines of West Germany for more than a decade and in this time sophisticated systems have been developed to ventilate them. The following is a description of the types of systems currently in use.

Tunnels driven by boring machines in W. Germany can be thought to consist of three discreet ventilation sections. The first section has one or two large diameter ducts which run almost the entire length of the tunnel, drawing fresh air from a through ventilation airstream outside the heading. This primary auxiliary ventilation system (primary system) supplies fresh air to a position outbye of the heading face (typically 100-200 m). From here it is moved up through the second section to the dust shield of the TBM by another series of ducts and fans (secondary system). The secondary system forces and/or exhausts air to/from the third section of the tunnel which is located between the dust shield and the heading face (head area). Figure 1 shows a diagrammatical representation of a TBM driven heading, giving typical dimensions for each of the individual sections; also shown is a further subdivision of the head area into two smaller zones (see HEAD AREA VENTILATION).

The ventilation in each of the three sections is now considered separately.

THE PRIMARY SYSTEM

All headings driven by full-face TBMs in West Germany have a forcing primary system. These have to date been used successfully to supply air to TBMs operating in excess of 5 km from the heading entrance.

The fans used to deliver air through the primary ducts are always sited outside the heading in a through ventilating airstream. By using high pressure fans at the inlet of the primary ducts, the need to stage fans at intermediate points is removed. It is debatable as to whether, with such high pressure fan configurations, sufficient air could be supplied down long lengths of a steel duct because of their inherent high resistance and large air leakage. The duct used in W. Germany is a heavy duty, woven polyester/nylon fabric with a PVC coating to prevent accumulations of static. This ducting is supplied in lengths from 20 m up to 300 m and can be packed in a small steel duct storage unit (cassette). The cassettes can be used with a wide variety of duct diameters (e.g. 1.2 m, 1.4 m, 1.6 m) and are refilled by the duct manufacturer. They are mounted on the rear of the pantechnicon which the TBM pulls along behind it (these may extend to 200 m behind the face); hence, as the TBM advances, the ducts are pulled from them. This system has many advantages over steel ducting, namely;

(i) a low duct friction factor (typically 35% lower than steel duct of the same diameter),

(ii) a low duct leakage coefficient (volumetric efficiencies are said to be between 70 and 90% with duct lengths greater than 3 km),

(iii) the positive pressure inside the ducts ensures that there is no leakage of return air in the tunnel into the primary system,

(iv) requires very little manpower to install (adjacent lengths of duct may be joined by either a coupling clamp arrangement as shown in figure 2a, or by means of a steel band and tensioned cables as shown in figure 2b),

(v) a continuous extension of the duct along with the TBM giving a more stable supply of air to the TBM.

The disadvantages of this system may be listed as follows:

(i) due to its non rigid nature the duct can only be used in a forcing system and cannot be converted into an exhausting system,

(ii) although fire resistant if exposed to flame the duct will disintegrate,

(iii) if punctured (e.g. by unshielded blasting in close proximity to the duct) it can prove difficult to re-seal the duct.

The ducts of the primary system are suspended from the support sets, offset from the centre (so as not to create a dead ventilation zone in the crown of the roadway) and are kept very straight (tight bends and restrictions are avoided) to keep the resistance to the flow of air as low as possible.

It is worth noting that the Chief Mines Inspectorate of Nothrhine-Westphalia now recommends that all headings which are driven by TBMs should have two, independently powered, ventilation ducts in their primary system.

SECONDARY SYSTEM

The current design of the trailing pantechnicons used with TBMs in West Germany does not provide sufficient space to accommodate the large diameter ducts of the primary system. Past experience has taught German TBM operators that if the nylon ducts are extended nearer to the face of the heading than the outbye end of the trailing pantechnicon then they become excessively damaged by the everyday work performed in that congested area of the tunnel. For this reason another system of ducts (the secondary system) is used to move the air forward from the storage cassettes of the primary duct.

The forcing ducts of the secondary system are generally smaller than those of the primary and in order that they do not obstruct the working platforms in the trailing pantechnicon they may have many sharp directional, area and cross-sectional profile changes. The ducts are, therefore, fabricated from lengths of reinforced plastic ducts joined together by lengths of steel ducts (channels) which are integrated into the trailing pantechnicon. This allows the system the flexibility it needs to absorb the movements caused by the advancement of the trailing pantechnicon.

The high virgin rock temperatures in which the German TBMs operate generally dictate that the forcing ducts of the secondary system include air cooling units. The high resistance of these units together with the ductwork, requires that such ducts have their own fan. However, some TBMs have an unobstructed secondary duct which is joined directly to the outlet of one of the primary ducts and these have no fan of their own.

The forcing ducts of the secondary system draw their air exhausted from the primary ducts; the usual joint between them being a 'butt' joint. If the secondary duct has its own fan then the joint is purposely made 'leaky' to allow the excess air not drawn by the fan an escape path. Air is then discharged near the dust shield either as an open jet and/or through Coanda ducts which discharge the air tangentially to the centre line of the duct (these are used extensively in areas of the tunnel where air velocities are low, e.g. in overlap zones and close to the face).

In addition to the forcing ducts which always end a meter or so before the dust shield, one or more extraction ducts are used to draw air from the head area of the TBM through openings in the dust shield. This creates a negative pressure inside the dust zone and thus fresh air is drawn into the head area of the TBM around the periphery of the head (see HEAD AREA VENTILATION). The return air in the exhausting ducts is passed through a dust extractor and sometimes an air cooler from where it is then discharged back into the main airstream of the tunnel. The location of this discharge point varies, but in most systems it is outbye of the cassettes.

In TBM headings, which are either excessively hot or dusty, short lengths of free standing ducts equipped with their own air cooler/dust extractor and fan may be used to provide localized air conditioning.

At high methane concentrations (> 1%) all electrical power is removed from the tunnel (see MONITORING AND MICROPROCESSOR INTERLOCK). In such situations, all electrically driven fans situated in the tunnel cease to function; hence the secondary system is shut down. Whilst a small volume of air may continue to flow from the primary ducts into the forcing ducts of the secondary system, this would do little to ventilate a methane laden head area. Therefore, in an attempt to overcome this problem, some of the German TBMs have the facility to temporarily blow air into the head area. Figure 3 illustrates how this is achieved by manual switching. A combination fan in the forcing duct of the secondary system is powered by electricity under normal operating conditions, but when electric power is removed it can be driven at a reduced flow rate by compressed air. This is used to move air from the cassettes up to the dust shield where it is re-routed into what was previously an extraction duct and forced into the dust zone of the TBM. The section of duct joining the forcing and extraction ducts (shown in figure 3) is a permanent fixture of the system, with the airflow through it controlled by a butterfly valve.

HEAD AREA VENTILATION

As has already been discussed, the head area of the German TBMs can be considered to comprise two separate zones;

(i) The Dust Zone - the area between the dust shield and the cutter head

(ii) The Cutting Zone - the area between the rear of the cutter head and the heading face

It is these two zones that are difficult to ventilate and hence it is in these that dangerous concentrations of methane have been observed to accumulate. The construction of TBMs currently used in the German coal mines (Robbins, Demag and Wirth) is such that whilst boring there is no means of advancing the ventilation ducting of the secondary system closer tc the heading face than the dust shield. Therefore, there is no attempt made to ventilate the cutting zone of the TBM directly. Instead, the dust zone is ventilated and a good interchange between the air in it and that in the cutting zone is hoped for.

The dust zone is ventilated by drawing the dust and methane laden air through the dust shield and into the extraction duct(s) of the secondary system. This way fresh air is drawn into the dust zone from tne tunnel via leakage paths in and around the dust shield. The location of the extraction ports, and any purposely created air leakage paths, in the dust shield are largely determined by the design of the TBM, and not by ventilation planning.

Under normal operating conditions (i.e. when the methane concentration in the exhaust airstream is less than 0.5%) the quantity of air extracted from the dust zone is high enough to ensure the safe dilution of methane in the head area, yet small enough to minimize the quantity of dust entrained into the extraction duct(s). When an increase in the methane make into the head area is detected (i.e. when the methane concentration in the exhaust airstream rises to above 0.5%) the quantity of air extracted is increased. The ventilation systems shown in figures 4a. & 4b. illustrate the two systems used to accomplish this. Figure 4a. shows the extraction duct with a second fan in parallel to the main extraction fan. This is used to boost the quantity of air drawn through the one exhaust port in the dust shield.

Figure 4b. shows the alternative arrangement whereby there is a second extraction duct complete with its own fan (drawing air from the dust zone through two different exhaust ports in the dust shield) installed, but inoperative under normal conditions.

The main leakage paths for fresh air flowing into the head area of the Robbins and Demag TBMs are a peripheral gap between the hydraulic pads (which press against the tunnel walls) and the dust shield, and the co..veyor opening provided for muck removal. The gap between the hydraulic pads and the dust shield varies depending on strata conditions, but on average is 6 cm, giving a leakage path area of approximately 1 m^2.

Although never scientifically tested, it is assumed that ventilation in the head area is enhanced by the rotation of the cutting head and the dust suppression sprays. These are both thought to add to the turbulence in the head area, thus improving the mixture of the methane and the ventilating air-stream. Therefore, it has been noted that in periods of high methane exhalation into the head area, rather than stop cutting completely, it may be more desirable to continue rotating the cutting head with little or no forward thrust.

MONITORING AND MICROPROCESSOR INTERLOCK

The West German Inspectorates have laid down very strict guidelines for the monitoring and control of auxiliary ventilation systems in headings (4). Generally for headings in which TBMs are used there are required to be 5 methane sensors, one located at each of the following positions:

(i) At the entrance to the heading in the free cross section of the roadway

(ii) At the duct storage cassette in the free cross section of the roadway

(iii) At the operator's console

(iv) In the crown of the roadway close to the dust shield on its outbye side

(v) In the extraction duct outlet of the secondary system

The sensors in positions (ii), (iii), (iv) and (v) have their signals fed to a microprocessor located in the trailing pantechnicon. This monitors the methane concentrations and sounds an alarm at the operator's console if a concentration greater than 0.5% is detected. It then automatically removes electrical power from the tunnel if the concentration rises above 1.0%. As well as feeding signals to the microprocessor, each methane sensor has its reading displayed visually on a meter and, unless linked to a mine telemetry system, the reading must also be recorded on either a paper chart or magnetic tape.

The regulations also require that sensors are used to monitor the air velocity and direction in some of the ventilation ducts and in parts of the free cross sectional area of the heading. These sensors are also linked into the microprocessor which is programmed to remove electrical power selectively from different areas of the tunnel (termed isolation zones) if air velocity falls below a predetermined value. More information about these isolation zones and the limiting air velocities may be found in the Guidelines of the Chief Mines Inspectorate of Northrhine-Westphalia (4).

In addition to the methane and velocity sensors there is also a requirement for two carbon monoxide sensors to be located in the tunnel, one at the entrance and the other at the rear of the trailing pantechnicon. Neither of these is linked into the microprocessor mounted on the TBM, but is monitored by the mine telemetry system if one is available.

Up to the present time the monitoring instrumentation in the tunnel has been powered directly from the TBM's own electrical supply. This is a non-intrinsically safe supply which has meant that in an emergency situation when power has been lost from the tunnel all of the instrumentation ceases to function.

EXAMPLES OF TBM VENTILATION SYSTEMS USED IN WEST GERMANY

During the authors' visit to West Germany three of the mines which use TBMs to drive tunnels were visited. Haus Aden Colliery and Prosper Haniel Colliery were both operating Demag TBMs of 6.5 m and 6.1 m diameter respectively and Westfalen Colliery a 6.1 m diameter Robbins machine. Both the TBM at Haus Aden and the one at Westfalen have experienced serious methane ignitions (a brief description of these is given in the section VENTILATION ASSOCIATED PROBLEMS).

The ventilation of these machines is now examined more closely, considering the comments of the operators as to the pros and cons of each.

Haus Aden Colliery - Demag 6.5 m, (figure 4a)

This primary ventilation system consists of two, 1.2 m diameter, nylon ventilation ducts which are extruded from cassettes, each of which contains 120 m of duct. The lengths of nylon duct are joined together by a steel ring tensioned cable arrangement (as shown in figure 2b) and to date run unbroken for a length of more than 4 km. The cassettes are mounted side by side on the rear of the trailing pantechnicon, some 125 m back from the face, with the ducts suspended from the steel sets by means of cradling belts. Attached onto the in-bye end of both the cassettes are 'leaky' transition pieces which guide the air into two separate forcing ducts of the secondary system each with its own fan. The air in each of these ducts is passed through cooling units and then discharged close to the rear of the dust shield (standing at the dust shield the draught from the forcing ducts can be felt). Air is drawn from the head area through a single exhaust port situated close to the top of the dust shield into the extraction duct of the secondary system. In non-gassy conditions only one of the two dust extractors is operated, drawing 2.5 m^3/s; in gassy conditions the other is also used in parallel to boost the extracted quantity to 4.5 m^3/s. Due to the hot conditions air coolers are positioned in the extraction duct to cool the return air. Localized cooling is supplied at a working platform in the trailing pantechnicon, approximately 140 m back from the face, by a free standing air cooler with its own fan.

Figure 4a contains a section through the tunnel at the dust shield. This shows the solid metal of the dust shield (hatched), the position of the extraction port (shaded black) and the leakage paths taken by the air entering the head area (white). Also shown are the two inspection hatches which were open at the time of, and as such the cause of one of the methane ignitions that occurred with this machine (see VENTILATION ASSOCIATED PROBLEMS).

Westfalen Colliery - Robbins 6.1 m, (figure 4b)

The primary system at Westfalen Colliery is similar to that used at Haus Aden; however there are some important differences in the secondary system.

The outlet of one of the two primary ventilation ducts is joined to a forcing duct of the secondary system which has its own fan (an 'active' duct) similar to those at Haus Aden. The outlet of the other duct is joined by an airtight transition piece to a length of 1.0 m diameter duct. This secondary duct has no fan of its own and instead relies on the pressure produced by the fans of the primary system to be sufficient to move air through it (a 'passive' duct). The advantage of this 'passive' duct being that air can be moved through it even if the electrical power has been removed from the tunnel. In addition, the secondary system also has a third forcing duct; this draws air from the tunnel outbye of the cassette and moves it up through the trailing pantechnicon and discharges it close to the dust shield.

In non-gassy conditions 3.3 m^3/s of air is extracted from the head area through a 0.5 m diameter duct and in gassy conditions a second extraction system pulls an additional 5.0 m^3/s of air through a 0.7 m diameter duct. The section through the dust shield in figure 4b shows the extraction ports through which air is drawn from the head. The smaller of the two extraction ducts draws air through a port located in the lower left quadrant, whilst the other draws air through two similar ports sited in the upper and lower right quadrants. The leakage paths into the head are similar to those of the Demag machine at Haus Aden, namely the conveyor opening and the peripheral gap, but it is thought that air leakage into the upper left quadrant is enhanced by the loose inspection hatch in that area.

The ventilation system of this machine has the ability to operate at a reduced capacity when there is no electrical power in the tunnel. The head area is ventilated by air which is re-routed from the 'passive' duct of the secondary system through to the larger of the exhaust ducts (by the method described in the SECONDARY SYSTEM) The fan of the free standing duct may also be operated at a reduced flow rate (5.0 m^3/s) by compressed air. These details are shown in figure 4b.

Officials at Westfalen Colliery did point out that it is difficult to operate this system without entraining large quantities of dust into the dust extractors. They think that this is because the air is extracted too close to the base of the dust shield where there is an accumulation of muck, and for this reason in non-gassy conditions the volume extracted from the head area is kept as low as possible.

Prosper/Haniel Colliery - Demag 6.1 m, (figure 4c)

The primary system of this TBM's ventilation system differs greatly from the other two. The primary system consists of a single 1.6 m diameter nylon duct. This duct is not supplied in cassettes, but comes in short 20 m lengths which are joined together with steel rings and tensioned cables. As cassettes are not used a direct joint between the primary duct and the forcing duct of the secondary system is not possible and instead they are overlapped. The inlet to the forcing duct of the secondary system is located at the rear of the trailing pantechnicon and from here air is moved up to the rear of the dust shield where it is cooled, then discharged through a Coanda duct and two open ducts.

Air is drawn from the head area through a single extraction port situated close to the top of the dust shield (the design of the dust shield is very similar to that of the Demag TBM at Haus Aden). The extraction system has two dust extractors in parallel enabling the exhausted air quantity to be varied according to conditions. The return air in the extraction system is then returned to the tunnel outbye of the inlet of the forcing duct.

At the time of the visit the TBM had advanced little over a kilometer from the heading entrance where it had intersected an accumulation of mud and water which had pushed the TBM 14 m back into the tunnel, temporarily suspending mining operations.

VENTILATION ASSOCIATED PROBLEMS EXPERIENCED BY WEST GERMAN TBM OPERATORS

FULL FACE TBMs

The incidents reported (references 9 to 12) cover several cases of methane ignitions in the cutting chamber of the TBMs by overheated machine parts or frictional ignitions. The incidents occurred on September 10, 1980 at Westfalen Colliery, on January 14 and 18, 1982, and again on July 19, 29 and 30 at the same Colliery and on March, 1982 at Haus Aden Colliery. In addition a mud and water incursion (14) occurred at Prosper-Haniel Colliery on September 16, 1982.

The incident on September 19, 1980 was shown to be caused by overheating (to 800 Deg. C) of two blocked disc cutters (9).

The incident on January 14, 1982 occurred as the TBM was driving through a tectonically disturbed area. Initial efforts with water hoses and fire extinquishers were unsuccessful. A major fire then developed igniting an adjacent coal seam. It could only be extinquished after extensive efforts by the mines rescue and fire-fighting team, involving the construction of a number of stoppings and the use, till January 23, 1982, of some 1,500,000 cubic metres of nitrogen (10).

The fire of March 11, 1982 at Haus Aden Colliery was, fortunately, far less serious. It could be that it was aggravated by an inopportune opening of an inspection hatch in the TBM dust shield (12) (see figure 4a).

The July 19, 29 and 30, 1982 gas fires at Westfalen were probably caused by frictional ignition of methane. There was a relatively high pyrite content in the rather broken sandstone mass being cut. The fires were controlled through the efforts of the shift workers with powder type fire extinquishers and water jets (11). The mud and water incursion at the Prosper-Haniel Colliery occurred on September 16, 1982 (14) whilst driving through a major water bearing geological disturbance (the Krudenburg fault). This fault had been driven through on previous occasions without any similar problems. On this occasion though water first started leaking into the heading and then around 19:15 hours on September 16 a major incursion occurred.

Since the inspection chambers in the dust shield were closed, the TBM was pushed back by the force of the mud and water some 14 m in 48 hours. Fortunately, the incursion occurred just as, but before, a team of miners was entering the cutting chamber to stem the water leak by grouting with cement. No casualties occurred, but the machine will not be operational before May, 1983. The remaining 7 or 8 m of disturbed ground will be driven by conventional drill and blast methods as soon as all of the muck has been cleared from the heading and the ground properly grouted.

ROAD HEADERS

Although the use of full face TBMs for driving headings in underground coal mines was of primary interest to the authors, the economic advantages of using roadheaders instead were also stressed by some of the personnel at the collieries visited. This is so if the headings are less than 3 km in length and if a number of these relatively short headings is to be driven at different locations. There is currently only one road header driving a heading in rock; however, a large number are being used for in-seam drivages.

SPECIAL ADVANTAGES OF THE LOVAT TBM CONSTRUCTION

The German hosts considered that the design of the Lovat machine may show some advantages over the construction of the Demag, Wirth and Robbins machines, namely:

(i) The ability to constantly introduce forced air into both the dust and cutting zones and the very direct method of exhausting air from them.

(ii) Hydraulic rather than electric drive of the cutter head; enabling regulation of cutter head rotation speed.

(iii) The ability to change disc-cutters from behind the cutting head.

(iv) Easier access to the face area through a relatively large central opening.

(v) The ability to produce sharper curves in the tunnel.

Other observations included the fact that there was some doubt whether the long, rigid, machine shell would be acceptable under German mining conditions where rapid tunnel convergence would probably jam it. Also, some concern was expressed as to whether the extra heat load generated by the hydraulic motors could be dissipated in their higher natural heat load conditions.

SUGGESTED IMPROVEMENTS AND CURRENT WEST GERMAN TBM SAFETY RELATED RESEARCH

Whilst in West Germany the authors spoke to many people who gave their opinion as to how the systems currently used to ventilate their TBMs could be improved. Although opinions varied the concensus seemed to indicate that the greatest weakness of their systems is their inability to force fresh air into the head area to mix, dilute and remove flammable concentrations of methane. By only extracting air from the head area the chances of there being a 'dead' zone in which methane can accumulate undetected are increased. It had been noted by operators of some of the TBMs, that upon examination of the tunnel face immediately after an ignition there are quite often cavities in which the methane could have been trapped. It is quite possible, therefore, that had air been forced right up to the face some of these incidents may not have occurred.

Given that they must continue using the extraction only systems (at least until some modification is made to the machine design) it is felt that the response time between having an increased methane make into the head area and detecting it in the exhaust duct should be shortened. The ventilation research engineers at WBK are, therefore, developing protective enclosures that will allow methane sensors to operate in the dusty environment of the extraction duct close to the dust shield. They have so far experimented with one such device that seems to show promise. The same research personnel have also developed a velocity measuring device that will operate at the same location (see Appendix II - 7).

Other West German researchers are looking at ways to monitor the disc-cutters to avoid the danger of over heating and to improve cutter performance (Appendix II - 17). Topics currently under investigation by them include:

(i) monitoring the speed of disc rotation,
(ii) monitoring the temperature of each of the discs and of their bearings,
(iii) cooling of the bearings,
(iv) improved visual monitoring of the discs,
(v) inerting the cutting head area with foam in the event of a dangerous situation

CONCLUSIONS

While a number of advantages accrue from driving headings in underground coal mines with full face tunnel boring machines (e.g. faster advance rates*, minimum disturbance of the adjacent rocks, reduced ground support requirements, far safer working conditions* and reduced resistance to airflow) it is also clear that stringent safety requirements must be adhered to in order to minimize the attendant risks. Particular attention must be paid to the risk of methane ignitions, caused by frictional sparking or overheated machine parts (e.g. cutting discs).

On the basis of a number of fires that have occurred in underground coal mines within the jurisdiction of the Chief Mines Inspectorate of Northrhine-Westphalia in West Germany, the latter have made the following recommendations:

(i) As a matter of principle the forced primary auxiliary ventilation systems used in full face TBM driven headings should be provided by two independently operated ventilation systems.
(ii) To ensure adequate dilution of the methane, one should ensure that the volume of the dust laden air extracted from the TBM's head area is as large as possible.

* These points in particular were stressed by several colliery personnel

(iii) Appropriate steps should be taken so that the purely extraction type ventilation of the head area presently in use can be instantly switched to forced type ventilation to ensure effective methane dilution and purging.

(iv) Adequate and reliable instrumentation should be provided to constantly monitor all airstreams as to their volume, flow direction, as well as methane content. Particular attention should be paid to the emergency situations when the electricity supply in the entire auxiliary ventilated heading has been interrupted due to inordinately high methane levels, which also renders the air monitoring instrumentation inoperative. In these cases it is advisable that intrinsically safe instrumentation be used with a telemetry system.

(v) All full face TBMs should be equipped with onboard fire extinquishers (high capacity powder type) with which any fires in the head zone can be positively extinquished. Manual activation from the machine operator's console is recommended.

(vi) Easier access to the cutter tools is absolutely essential. One should be able to control and examine the cutter discs without having to enter the cutting zone.

(vii) Improved cooling of the cutters is a necessity. Thermal monitoring of the cutter discs is also recommended.

(viii) All full face TBMs should be integrally equipped with drilling equipment able to bore a number of 10 m long pilot-holes in advance of the face. The purpose of these holes is to test for coal seams, faults, and to provide a means for methane drainage.

(ix) The use of full face TBMs and boom type roadheaders is strictly prohibited in areas where the danger of gas outbursts exists.

Other important details such as permissible ventilation volumes, permissible methane concentrations, recommended ventilation layouts, basic machine advance rates, etc., have also been reported.

METHANE FLOW RATES

From the German documentation it appears that their practise is to initiate a warning system at a 0.5% methane concentration and to discontinue cutting operations at 0.7 to 0.8%. At a methane concentration of 1.0% all electrical supply is cut off to the heading (16). Alternatively, a warning is sounded at 0.7 to 0.8%, at which point cutter head rotation is continued, but without any forward thrust. Again at 1.0% the electrical supply is cut off, with consequent stoppage of the dust collectors, most measuring instrumentation, etc. (5). Only under exceptional circumstances, such as unexpectedly high gas makes when the gas concentration just cannot be kept below the 1.0% limit can temporary permission be granted for local concentrations of up to 1.5%, under strictly controlled conditions (8, 15). This temporary situation does not, however, apply to the TBM driven situations of interest.

FIRE RISK CONTROL

The German regulations regarding fire fighting equipment are rather specific and demanding (5). They state for example that large capacity powder type fire extinquishers should be mounted on board the TBM for filling the entire head area.

There should also be provision for rapidly activating this equipment, preferably by the machine operator simply pressing a button. As an example, twelve extinquishers of 10 kg each are mentioned in appendix 5 of reference 6.

Moreover, from German experience it was concluded that water sprays must also be provided on the TBM, partly in the shape of nozzles for blanketing the head area (principally for dust control and cutter cooling) and partly as an intensive sprinkler system, covering the TBM areas behind the dust shield (as illustrated in appendices 2 and 3 of reference 6), for fire fighting purposes.

In an attempt to standardize heading ventilation, the Chief Mining Inspectorate of Northrhine-Westphalia has compiled a lengthy and comprehensive document on this subject (4). This is a useful guide covering the parameters which need to be considered when designing an auxiliary ventilation system. Copies of this may be obtained from the authors.

ACKNOWLEDGEMENTS

Special thanks are due to Mr. W. Marth of the Chief Mines Inspectorate of Northrhine-Westphalia who first supplied copies of an extensive range of documentation to the authors (reference 3 to 5, 9 to 12, 14) and whose tireless efforts then enabled the authors to visit the numerous mines, safety, rescue and research stations listed in Appendix

The authors also wish to express their grateful acknowledgements to the large number of people (listed in Appendix I) who freely gave of their time and unique experience in the special field of interest. Sincere appreciation is due to the mine managers and divisional chiefs for permitting the visits to take place and for the many special courtesies extended. Mention must also be made of the extensive documentation provided which will be of considerable interest and assistance (see Appendix II).

REFERENCES

1. Palmer, J.H.L., Cox, W. and Lovat R. "Construction and Performance of a Canadian Rock Tunnel Boring Machine"; Proceedings 14th Canadian Rock Mechanics Symposium, Vancouver, May 12, 1982.

2. Gillman, J.J. 'Donkin-Morien Development Project"; CIM Bulletin, Vol. 75, No. 845, pp. 133-137, September 8, 1982.

3. "Mine Regulations of the Chief Mine Inspectorate of Northrhine-Westphalia (BVOST) dated February 20, 1970", Section 13, para. 141 to 168 on Ventilation (in German).

4. "Guidelines of the Chief Mines Inspectorate of Northrhine-Westphalia on the Installation, Operation and Monitoring of Auxiliary Ventilation Systems in Coal Mines dated December 22, 1980", ref. 18.31.3-1-12 (in German).

5. "Safe Driving of Headings in Coal Mines with Full Face TBMs -- Avoiding Methane Ignition", Circular 18.43.1-5-9 dated March 31, 1982, of the Chief Mines Inspectorate of Northrhine-Westphalia (in German).

6. "Guidelines on Self-Rescue, Rescue and Fire Protection Techniques when Driving Auxiliary Ventilated Headings with Full-Face TBMs", Steinkohlenbergbauverein, Circular MZ22 of December 20, 1982, by Heising and Kock (in German).

7. "Minutes of Discussions on July 27, 1982, re. Fire Safety Measures when using TBMs at Colliery Westfalen on August 2, 1982", Mine Directorate Westfalen (in German).

8. "Guidelines of the Chief Mines Inpectorate of Northrhine-Westphalia on Granting of Exceptions for CH4 Contents of up to 1.5% in the Air within the Full Cross-Section of Retreat Mining Operations", ref. 18.3-1-6 dated April 30, 1976 (in German).

9. "Completed Questionnaire of the Chief Mines Inspectorate of Northrhine-Westphalia re. the September 19, 1980, Gasfire on the 1035 m Level of Colliery Westfalen", ref. 18.41.3-6-26 (in German).

10. "Summary Report re. the January 14, 1982, Gasfire on the 1035 m Level of Colliery Westfalen", Chief Mines Inspectorate of Northrhine-Westphalia, ref. 18.41.3-8-6 dated March 8, 1982 (in German).

11. "Investigation Report re. the July 19, 29 and 30, 1982, Gasfires on the 1035 m Level of Colliery Westfalen", dated at Hamm, October 1, 1982 (in German).

12. "Investigation Report re. the March 11, 1982 Gasfire on the 940 m Level of Colliery Haus Aden", dated at Kamen, June 9, 1982 (in German).

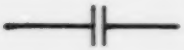
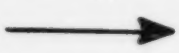
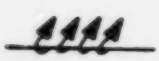
13. "Special Operating Plan C-1-3/82 of March 24, 1982 and Additions thereto (NF/C-1-3/82, dated June 28, 1982) for Driving a Heading at the 940 m Level of Colliery Haus Aden", dated at Kamen, September 20, 1982 (in German).

14. "Short Report on the September 16, 1982, Water and Mud Incursion on Level 6 of Colliery Prosper/Haniel", Chief Mines Inspectorate of Northrhine-Westphalia, ref. 18.22.1-9-9, dated October 22, 1982 (in German).

15. Siebers and Dickmann "Ventilation Monitoring within the Framework of the Guidelines of the Chief Inspectorate of Northrhine-Westphalia on Granting of Exemptions for CH4 Contents (ref. 18.3-1-6 of April 30, 1976) in case of Different Mine-Layout Situations", Bergbau, pp. 454-458, 1977 (in German).

16. Kilborn Ltd. "Report on Ventilation Procedures for a 25 ft. Diameter Tunnel Borer in Potentially Gassy Mine Development", February, 1983.

TABLE 1

	Butterfly Valve
	Fan
	Ventilation Duct
	'Leaky' joint between two lengths of duct
	Duct Storage cassette
	Dust extractor
	Air Cooler
	'Open' outlet of ventilation duct
	Coanda duct (swirl duct)

Definition of Symbols used in ventilation line diagrams

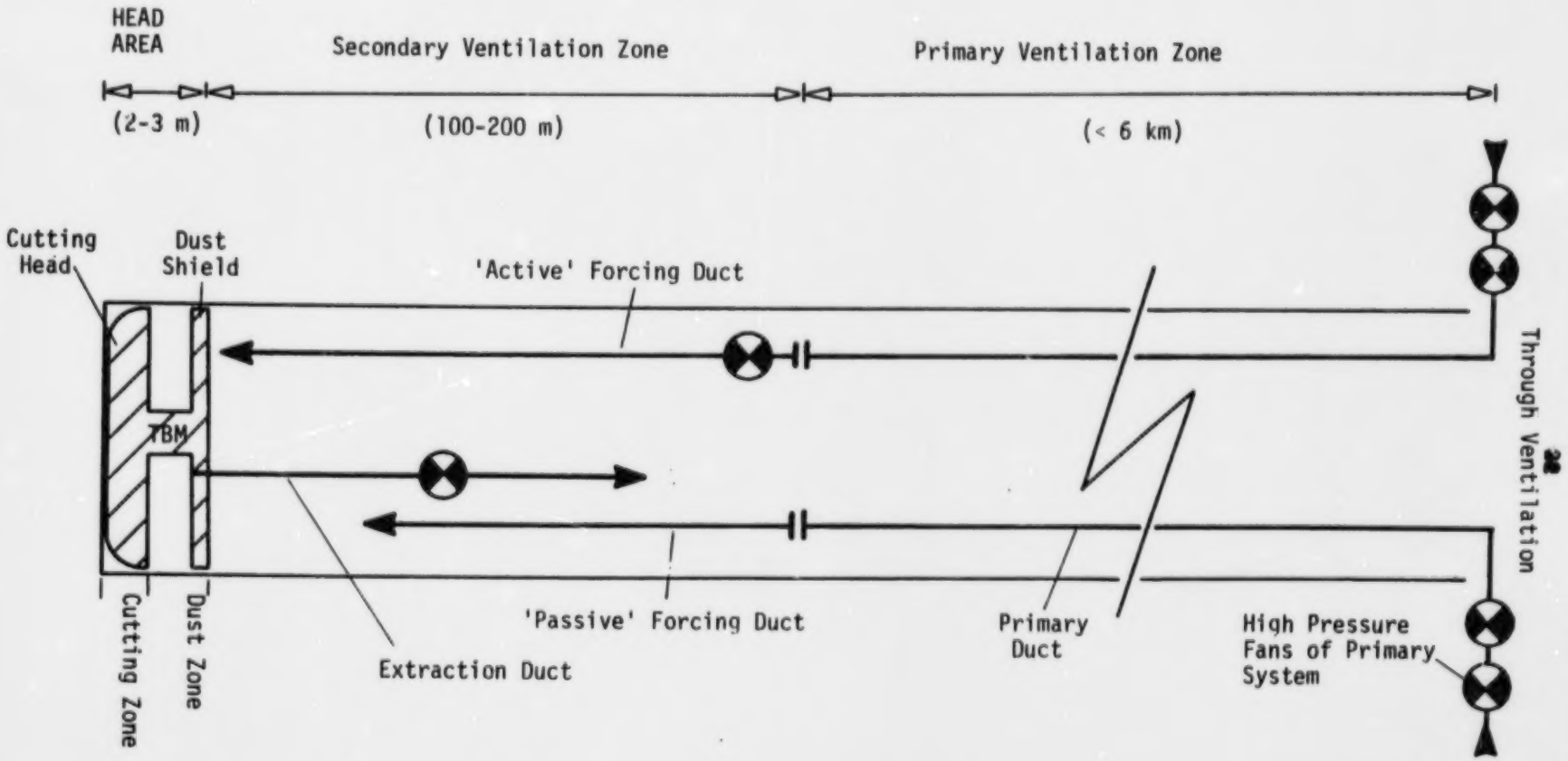


Figure 1. Illustration of the Three Ventilation Zones of a TBM Driven Heading

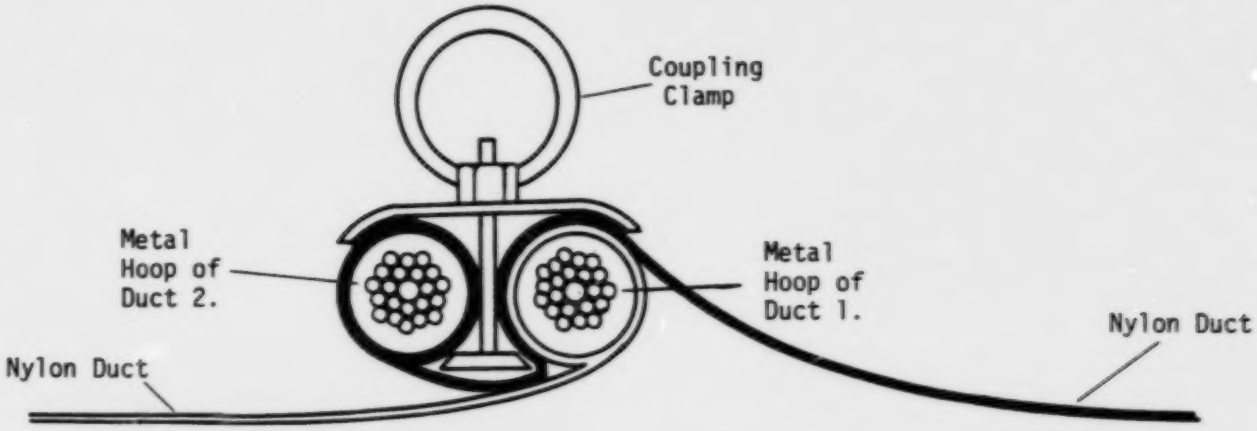


Figure 2a. Coupling Clamp Arrangement for Joining Ventilation Duct

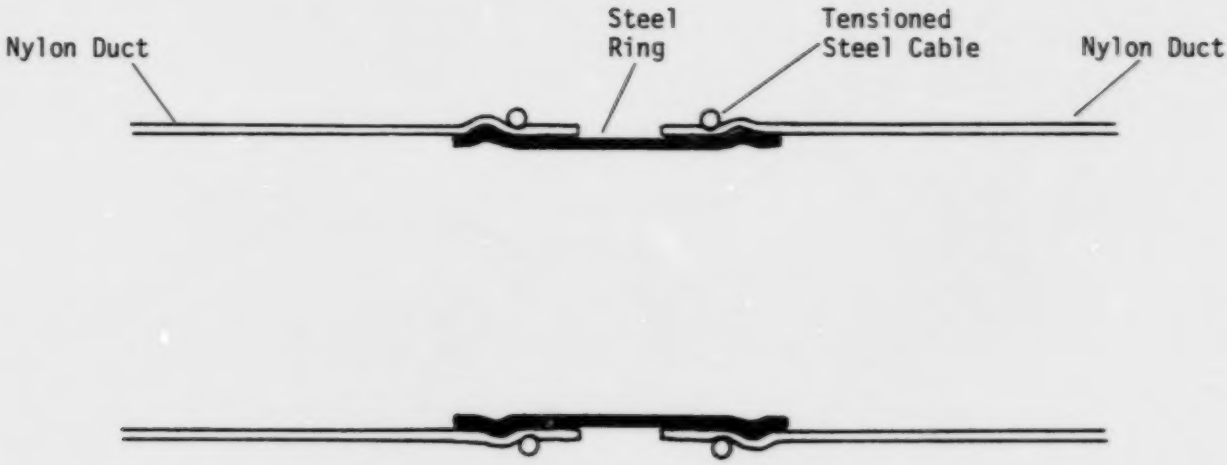


Figure 2b. Steel Ring Plus Jubilee Type Method for Joining Duct

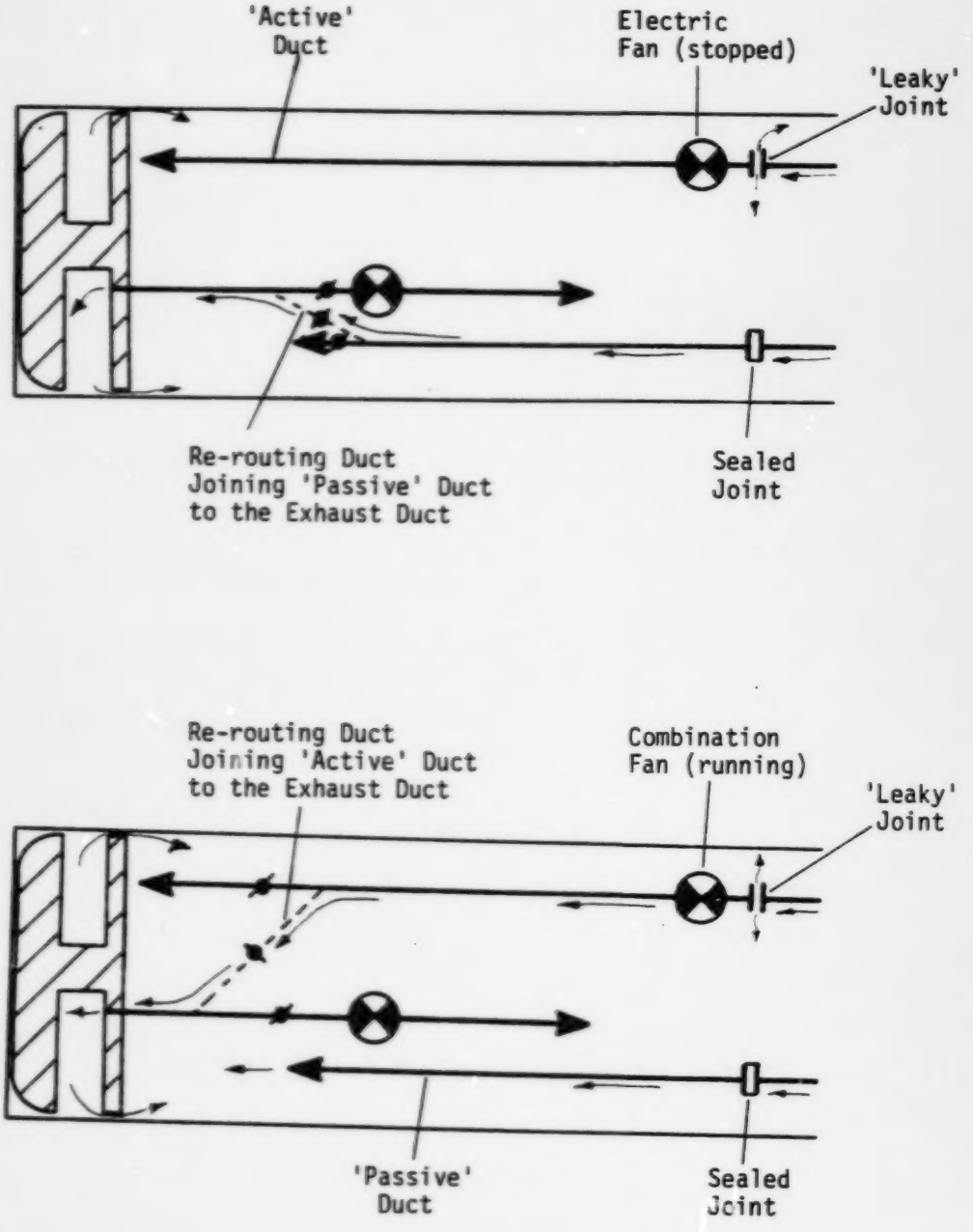
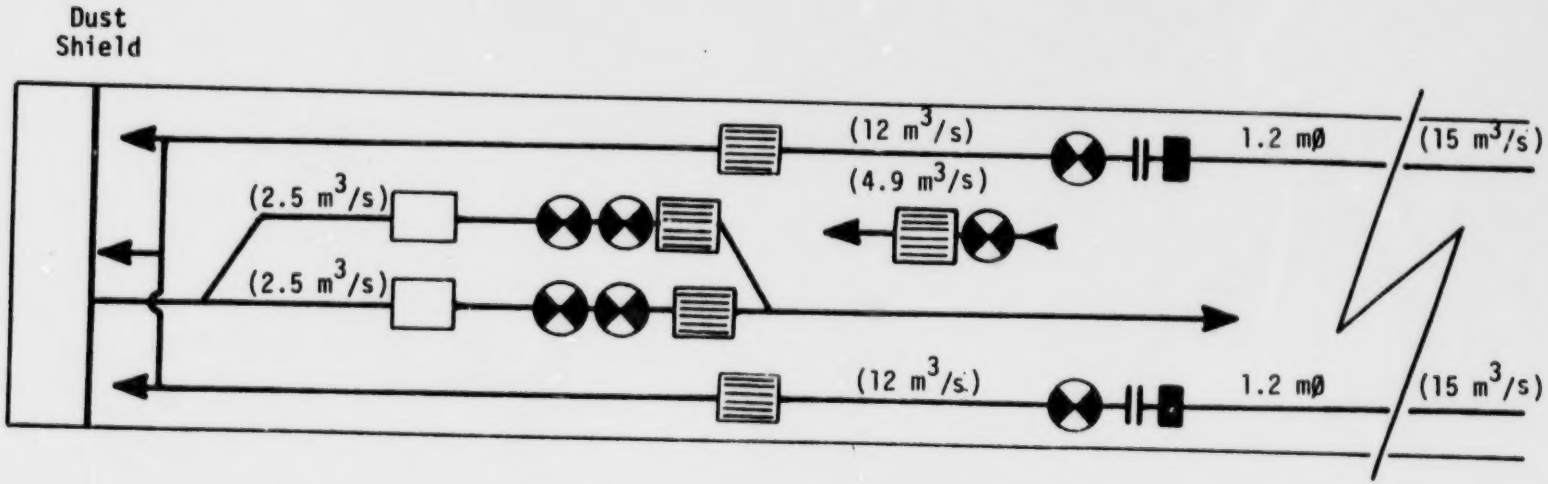


Figure 3. Two Alternative Systems for Supplying A Reduced Airflow to Head Area of W. German TBM's in Emergency Situations



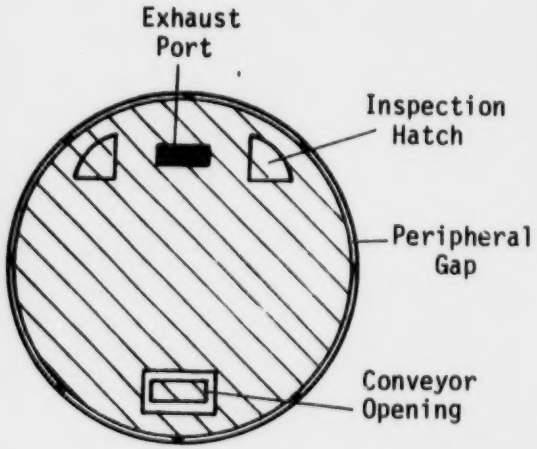
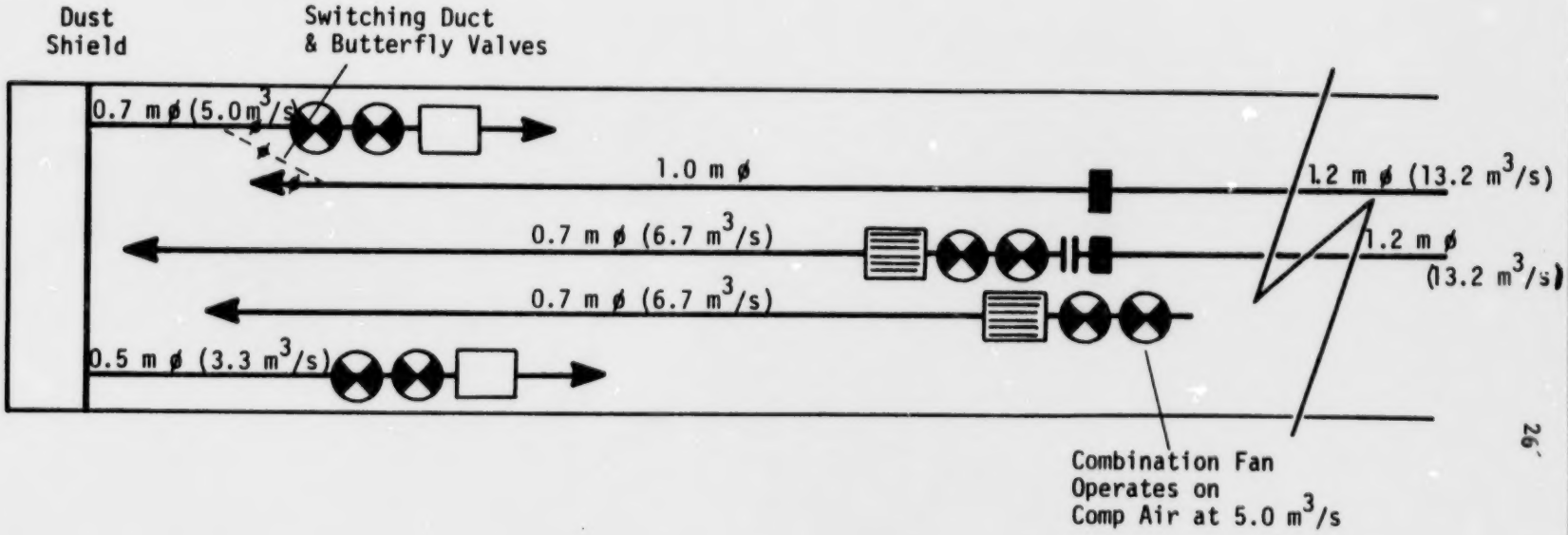


Figure 4.a. Sketch illustrating ventilation of 6.5 m Ø Demag TBM at Haus Aden Colliery



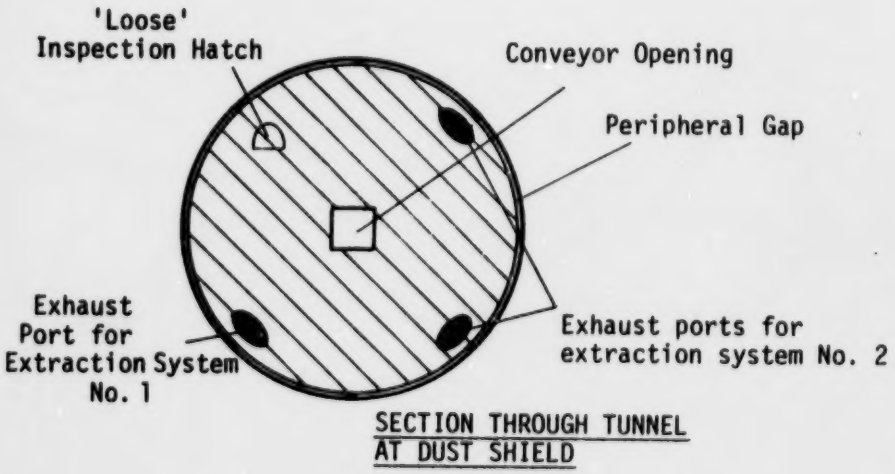
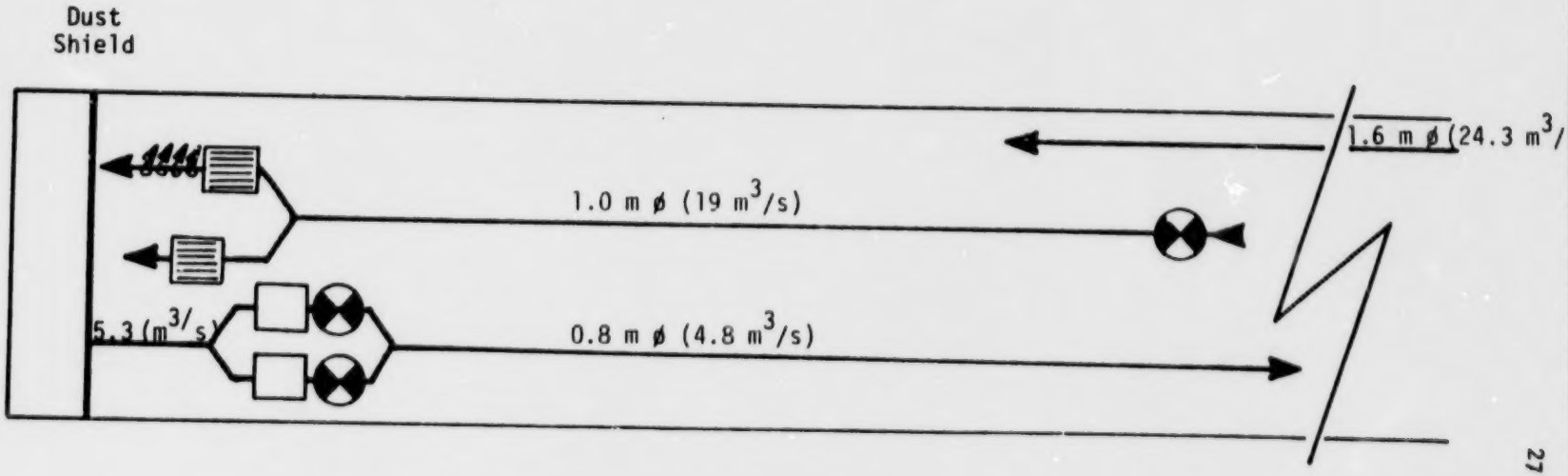


Figure 4.b. Sketch illustrating ventilation of 6.1 m ø Robbins TBM at Westfalen Colliery



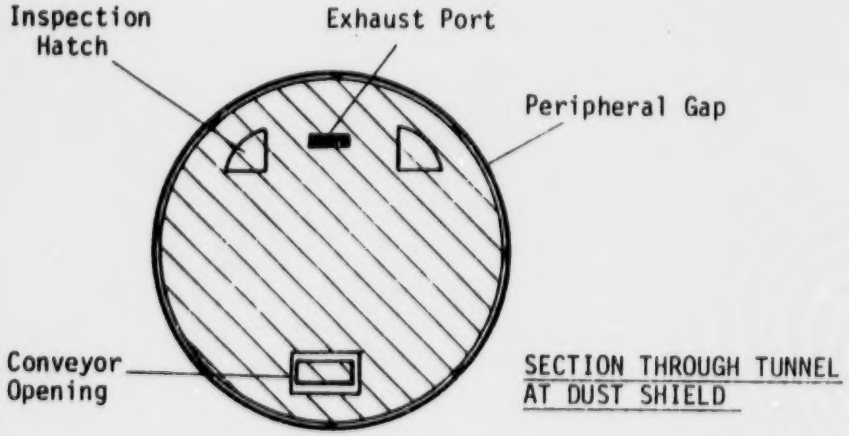


Figure 4.c. Sketch illustrating ventilation of 6.1 m ø Demag TBM at Prospier/Haniel Colliery

APPENDIX I

Schedule of Visits arranged for the Authors
by the Mines Chief Inspectorate (LOBA) of
Northrhine-Westphalia (N.W.), March 7 to 11, 1983

Date	Location	Participants	Subject of Discussions
Monday March 7 a.m.	Conference Room, Mines Chief Inspectorate of N.W., Dortmund	Messrs. Pilgrim - Vice President Palm - Division Chief Marth - Mine Director responsible for U/G fire and expl. protection. Siebers - Mine Director responsible for Vent. & Gas make. Mönch - Mine Director responsible for Mine Layout. Traeger - Mine Director responsible for mechanical equipment.	Brief description of each other's respective work areas. Description of major Lovat TBM and heading layout features at CBDC. Review of proposed ventilation layout.
Monday March 7 p.m.	Essen Mine Rescue Organization Headquarters, Office of the Chief	Messrs. Kock - Chief Both - Assistant Chief Marth - Mine Director, LOBA, N.W.	Firefighting & Mine Rescue in case of TBM driven headings.
Tuesday, March 8, a.m.	Colliery Haus Aden of Bergbau A.G. Westfalen at Bergkamen-Oberaden	Messrs. Lappe - Mine Manager Rebbeck - U/G Manager Katzorke - Contractor's Consortium Krings - District Mines Inspectorate Marth - LOBA, N.W.	Review of general mine layout; TBM driven heading layout; TBM ventilation characteristics combined with U/G visit.

Date	Location	Participants	Subject of Discussions
Tuesday March 8 p.m.	Colliery Westfalen of Eschweiler Bergwerks-Verein at Ahlen	Messrs. Briele - Mine Manager Bossmann - U/G Manager Dr. Wiesner - Chief Executive Schweinberger - Ventilation, Mine Layout Marth - LOBA, N.W.	Review of Mine-layout, TBM and Ventilation problems
Wednesday March 9 a.m.	Mine Ventilation Test Station, WBK, Bochum	Messrs. Schubert - Director Dr. Graumann - Chief of Instrumentation and Auxiliary Ventilation Dr. Noack - Instrumentation Siebers - LOBA, N.W.	Detailed discussions of relevant ventilation and instrumentation problems
Wednesday March 9, p.m.	Machinery-technique Institute, WBK, Bochum	Messrs. Marx - Chief Investigator Radtke - Assistant Investigator Siebers - LOBA, N.W.	Review of methods for lowering ignition risks in gassy atmospheres
Thursday March 10 a.m.	Colliery Rossenray of Bergbau AG Niederrhein at Moers	Messrs. Boldt - Mine Manager Erdtmann - District Mine Inspectorate Mönch - LOBA, N.W.	Review of general mine layout; Road-header driven heading layout; Road-header operating and ventilation problems.
Friday March 11 a.m.	Colliery Prosper-Haniel of Bergbau AG, Niederrhein at Bottrop	Messrs. Ketteler - Mine Manager Heiermann - U/G Manager Plenge - Ventilation Kühnemann - Contractor's Consortium Breidung - District Mine Inspectorate Klaker - District Mine Inspectorate Mönch - LOBA, N.W.	Review of general mine layout; TBM and ventilation problems; special water and mud incursion problems; combined with U/G visit.

APPENDIX II

List of documents supplied (in German) during March 1983 field trip to Northrhine-Westphalia collieries, laboratories and mine inspectorates.

1. "1981 Annual Report of the Mine Inspectorates of Northrhine-Westphalia", by the Ministry of Industry, Medium size Industrial Enterprises and Transport, Düsseldorf, 69 pp. 69 (1981).

2. "1981 Annual Report of the Essen Mine Rescue Organization Headquarters", by the Bergbauforschung GmbH, Essen, 44 pp. (1981).

3. R. Wesely "Ventilation monitoring in the face area of headings"; Ph.D. Thesis, Dept. of Mines and Smelters, Tech. University of Aachen, 129 pp. (1983).

4. "1981 Annual Report of the Westfälische Beggewerkschaftskasse WBK, 168 pp. (1981).

5. "Extract from the 1981 Annual Report by WBK - Mine Ventilation Test Station", WBK, 21 pp. (1981).

6. Dupre, G., Graumann, K. "Ventilation in the area of Tunnel Boring Machines with Dust Collectors, Part I & II", Bergbau No. 5, pp. 188-196 and pp. 266-272, May/June 1978.

7. Graumann, K. and Gastberg, I., "Back-up Disc with Impingement Head for monitoring the dust laden supply air of dust collectors in TBM driven Headings", Glückauf - Forschungs Hefte, Vol. 44, booklet 4.1, pp. 17-19, (1983).

8. Graumann, K. and Kasten, F. "Monitoring of Airstreams in Headings"; Bergbau No. 8, pp. 414-418 (1982).

9. Graumann K. et al "Microprocessors monitor Auxiliary Ventilation in TBM driven Headings", Glückauf, Vol. 118, No. 16, pp. 845-848 (1982).

10. Ventilation Diagrams of Auxiliary Ventilated Headings at Colliery Prosper/Haniel and elsewhere with examples of test forms.

11. "75 years of the Mine Ventilation Test Station - 1903 to 1978" WBK, Bochum, 97 pp. (1978).

12. Loehr, P. "TBM driven headings at Lohberg Colliery", Bergbau, No. 1, pp. 8-10 (1983).

13. Henneke, J. and Kuebler, H. "Mechanically Driven Headings", Bergbau, No. 1, pp. 10-14 (1983).

14. "The Eschweiler Bergwerks-Verein AG, Mines Directorate Westfalen", Information Booklet, 21 pp.

15. Set of four drawings to illustrate DEMAG TBM used at Westfalen Colliery.

16. Five illustrated leaflets on PAURAT - Roadheader models E134, E169, E195 and E200, in use at colliery Rossenray.

17. Illustration and Dimensions of water jet nozzles used on TBMs in headings underground.

18. Boldt, H. "Heading Advance Techniques and Advance Investigation of local conditions as the basis for optimum mining conditions in the West German hard-coal mining industry", Glückauf, Vol. 114, No. 3 pp. 98-108 (1978).

19. Boldt, H. "Development and Initial operating experiences with a roadheader driving headings in rock", Glückauf, Vol. 118, No. 3, pp. 127-134 (1982).

20. Boldt, H. "6000 m of full face headings driven in the coal mines on the left of the Rhine", Rock Mechanics, Supplement 6, pp. 147-160 (1978).

21. Guntau, A. "Ventilation of Machine driven headings - problems and solutions", Der Leitende Angestellte, No. 5, pp. IX-XVII, (1979).